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SIMULATION STUDIES OF POTENTIAL EFFECTS FROM ATIKOKAN TGS ON WALLEYE EGGS

Report No 86-290-K

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ABSTRACT

Computer simulations run using 1985 temperature data determined egg incubation periods, and hence the length of time that flow provisions are required, for walleye spawning at the Snow Lake outlet downstream from Atikokan TGS. Ambient temperature simulations indicated completion of hatch by May 31 for a late (May 11) spawning date. Assuming a ΔT of at least 5 C^{o}, hatch would be complete by May 23. Simulations indicated best egg survival with a ΔT in the 3-5 C^{o} range, but predicted temperature rises are in excess of 8.4 C^{o} with 2-shift operation. Such temperatures may deleteriously affect egg survival, especially if spawning occurs as late as May 11. Detailed field monitoring of Snow Lake outlet temperatures, walleye spawning times and hatch success are recommended to determine whether these potential impacts are occurring.

job	file	date	report no.
34-134-40192	837.321ATI	February 17, 1987	86-290-K

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EXECUTIVE SUMMARY

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This report describes computer simulations run to determine egg incubation periods, and hence the length of time that flow provisions are required, for walleye spawning at the Snow Lake outlet downstream from Atikokan TGS. Results based on 1985 ambient temperatures indicate that early spawned walleye (April 27) would complete hatch by May 25, while late spawned eggs (May 11) would complete hatch by May 31. The effects of heat additions from station operation were examined in detail. Assuming that the ΔT will be at least 5 C^{o}, flow should be maintained until at least May 23.

Simulations run using ambient temperatures for the outlet of Ski Lake (a small lake draining into the cooling lake chain at Icy Lake) indicated earlier hatch dates and better survival. At the Snow Lake outlet, "ambient" temperatures were clearly sub-optimal, as the station operated CCW pumps with little or no heat input. Predicted survivals ranged from 23% (April 27 spawning) to 32% (May 11 spawning).

Further simulations indicated optimal survival (43%) with a 5 C^{o} ΔT for eggs spawned on April 27. Best survival would be 38% with a 3 C^{o} ΔT for eggs spawned on May 11. Computations by R. Elliott indicate that with a two-shift operation, Snow Lake outlet temperatures may be elevated by at least 8.4 C^{o}. Present simulations indicate this ΔT would reduce survival of early spawned eggs (April 27) to about 25%, while survival of late spawned eggs (May 11) would be reduced to about 8%. Detailed field monitoring of Snow Lake outlet temperatures, walleye spawning times and hatch success are recommended to determine whether these potential impacts are occurring.

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SIMULATION STUDIES OF POTENTIAL EFFECTS FROM ATIKOKAN TGS ON WALLEYE EGGS

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1.0 INTRODUCTION

Walleye are known to spawn at several locations within the cooling lake chain at Atikokan TGS (Ontario Hydro Research Division Report No 86-38-K). Previous laboratory studies determined the thermal requirements of developing walleye (Stizostedion vitreum) eggs (Ontario Hydro Research Division Report No 81-77-K). Computer models developed in that study may be used to assess potential effects of varying temperature regimes on walleye spawning. At the request of the Environmental Studies & Assessments Department, computer simulations were run (using 1985 temperature data) to determine the period of egg incubation, and thus the length of time that flow provisions are required, for walleye spawning at the outlet of Snow Lake. The computer simulations also provided useful insights into possible effects of various station operational procedures on hatching success of walleye eggs. Comparative simulations were also run for a spawning site (Ski Lake outlet) which will not be directly affected by the station thermal discharge.

2.0 METHODS

2.1 Development of the Simulation Models:

The incubation study indicated that the sensitivity of walleye eggs to thermal stress changed during embryonic development (Ontario Hydro Research Division Report No 81-77-K). Two distinct blocks of embryonic time were recognized. The first included from fertilization to developmental stage 9 (free tail-bud) and was characterized by relatively high mortality at all

temperatures. Survival was near optimal (40 to 48%) over the 11 to 17°C range, declining to near 20% at 20°C and near 0% at 5°C. During later embryonic development (stage 9 to completion of hatch at stage 20), survival ranged from 90 to 100% over a 9°C to 15°C optimum and declined sharply at higher and lower temperatures, reaching about 40% at 4°C and near 0% at 20°C. In order that the results might be used to predict effects in seasonally changing thermal regimes, separate regression models relating survival to temperature were fitted for each of the blocks of embryonic time described above. Similar models were also developed relating temperature to the number of days required for completion of each developmental block.

The laboratory models were developed to predict effects in both constant and repeatedly fluctuating thermal regimes. Temperature cycles were repeated on a daily basis, resulting in eggs being exposed to cycle temperatures for 6 hours/day and base temperatures for 18 hours/day. Models fitted to the data had the following general form:

$$Y^{\gamma} = b_0 x_0 + b_1 x_1^{\alpha 1} + b_2 x_2^{\alpha 2} + b_{11} x_1^{2\alpha 1} + b_{22} x_2^{2\alpha 2} + b_{12} x_1^{\alpha 1} x_2^{\alpha 2}$$

Where:

Y = observed response (% survival, development time)

x_1 = base temperature °C (18 hours/day)

x_2 = cycle temperature °C (6 hours/day)

$\alpha 1$, $\alpha 2$, γ = power transformations selected by an iterative procedure converging on transformations yielding a minimum residual variance.

These models were used in the present study to predict effects on walleye spawning in the Atikokan TGS area. For these simulations, daily mean temperatures (recorded by Geotechnical and Hydraulic Engineering Dept) were used as input values.

2.2 **Simulation Procedures**:

Beginning with the date of fertilization, the expected percentage of Block 1 development during this day was computed from the Block 1 development model, assuming equal base and cycle temperatures (the ambient temperature on this day). This calculation was repeated for each successive day and results accumulated until the calculations indicated that developmental

Block 1 was complete. Then the Block 2 development model was used until calculations indicated completion of hatch. For each daily interval used in the simulation, the appropriate Block 1 or Block 2 survival model was used to compute and accumulate the expected mortality.

The simulation procedure was programmed for use on a Sinclair "QL" microcomputer. The program allowed successive runs on each set of input (temperature) data, altering start (spawning) dates, base temperatures and cycle temperatures without data re-entry. As the regression models were based on repeated daily temperature cycles, reasonable predictions could be made of the effects of intermittent station operation (one, two or three shifts/day). Thus, elevating cycle temperatures (for 6 hours/day) was comparable to one shift/day (8 hour) operation and elevating base temperatures (18 hours/day) was comparable to two shift (16 hour) operation, assuming that cooling water pumps were operated continuously, resulting in rapid return to ambient temperatures. The conditions resulting from continuous plant operation (three shifts) or two shift operation without the use of CCW pumps during the off-shift was simulated by elevation of both base and cycle temperatures. The temperature regime assumes no damping effect from storage or surface heat transfer in Snow Lake. Therefore, it is a conservative 'worst case' scenario.

3.0 RESULTS AND DISCUSSION

3.1 Effects of Spawning Dates and Temperature on Hatching Dates:

During 1985, ripe walleye were first observed at the outlets of Snow Lake and Ski Lake on April 27. It is believed that spawning occurred on or shortly after this date. However, in previous years, spawning activity has been observed extending well into May (Haymes, pers. comm.). Therefore, a series of simulations was run, assuming spawning dates ranging from April 27 to May 11 (May 16 for Ski Lake outlet). Results (Figure 1) indicate that eggs spawned at the Snow Lake outlet on April 27 would have completed hatch by May 25. Delay of spawning by two weeks (to May 11) would result in completion of hatch by May 31, a difference of only 6 days, as eggs spawned at the later date would experience warmer temperatures, and hence, accelerated development.

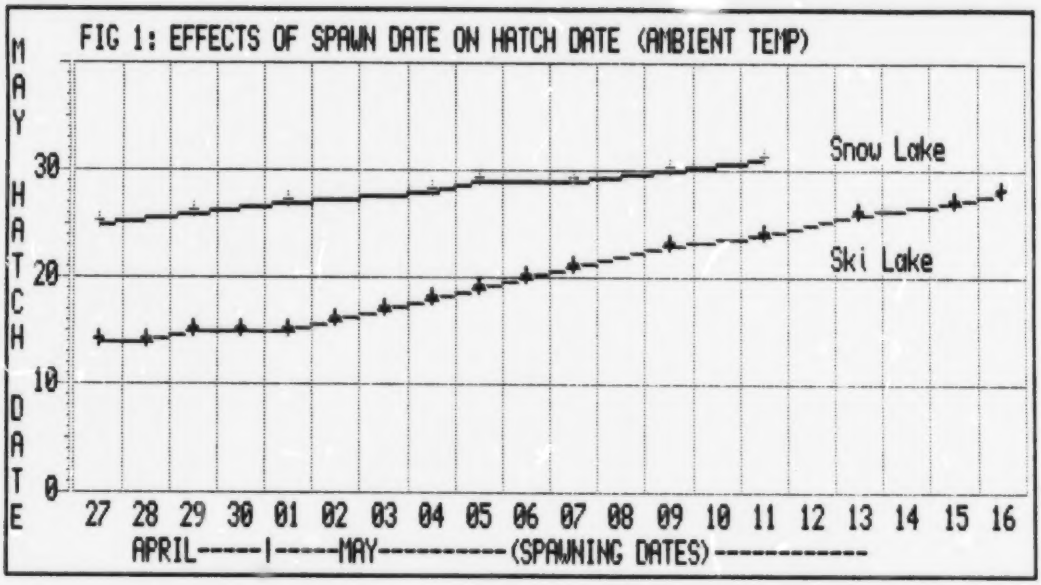
FIG 1: EFFECTS OF SPAWN DATE ON HATCH DATE (AMBIENT TEMP)
MAY HATCH DATE
0
10
20
30
Snow Lake
Ski Lake
27 28 29 30 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16
APRIL-----|-----MAY----------(SPAWNING DATES)----------

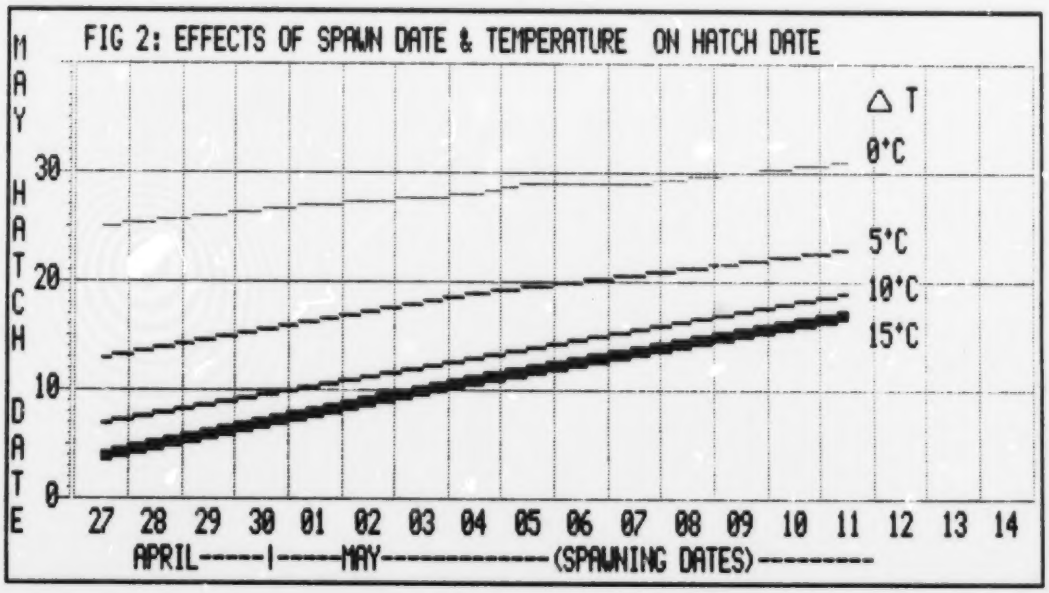
FIG 2: EFFECTS OF SPAWN DATE & TEMPERATURE ON HATCH DATE
MAY HATCH DATE
0
10
20
30
△ T
0°C
5°C
10°C
15°C
27 28 29 30 01 02 03 04 05 06 07 08 09 10 11 12 13 14
APRIL-----|-----MAY----------(SPAWNING DATES)---------

Temperatures at the Ski Lake outlet were very low (4.7°C) on April 27, but warmed rapidly due to the limited volume and small drainage basin of Ski Lake. Thus, the predicted hatch date (May 14) is well before that of the Snow Lake fish. For Ski Lake fish, delay of spawning by two weeks (to May 11) would result in completion of hatch by May 24, a delay of 10 days.

Further simulations were run with the Snow Lake data to determine likely hatch dates once Atikokan TGS begins operation. Results are shown for ambient temperatures and a range of continuous temperature increases (to 15 C°) in Figure 2. Advancement of hatch dates would be greatest for early spawners (April 27) due to the cooler ambient temperatures prevailing at this time. Thus, eggs spawned on April 27 and exposed to a 10 C° temperature rise would hatch on May 7, an advancement of 18 days. Those spawned on May 11 (with a similar temperature rise) would hatch on May 19, a twelve day advancement.

3.2 Effects of Spawning Date and Temperature on Egg Survival:

3.2.1 Ambient Temperatures

The effects of spawning date on survival of walleye eggs at ambient temperatures are shown in Figure 3. In this figure, "Spawning temp" refers to the temperature on the date of spawning, while "Hatch temp" refers to the temperature on the date when hatch was complete for each group. Comparison of the two values thus gives a general indication of the temperature range experienced during incubation. Results for Ski Lake (Figure 3a) indicate a substantial increase in egg survival if spawning were delayed 3 to 4 days, until temperatures reached about 10°C. Survival would remain high (>35% hatch) for spawning dates up to May 9, as incubation temperatures would generally approximate the upper portion of the 10 to 15°C optimum for walleye incubation. The progressive decline in survival predicted for later spawning dates (May 10 to May 16) is the result of above-optimal temperatures (>15°C), which would be experienced by late-spawned eggs.

Quite different results are predicted for fish spawned at the Snow Lake outlet (Figure 3b). The Snow Lake temperatures observed in 1985 are the result of CCW pump operation with little or no station heat input. Thus, these "ambient" temperatures more properly reflect warming trends of CCW inlet waters (Moose Lake, Marmion Lake) and probably warm more slowly than pre-construction temperatures for Snow Lake. The spawning temperatures observed at the Snow Lake outlet were therefore well below the optimum for walleye development. The simulations indicate that hatch would be only 23% for eggs spawned on April 27. Delay in spawning would result in a gradual survival increase, reaching 32% for eggs spawned on May 11. Ambient temperatures during later development

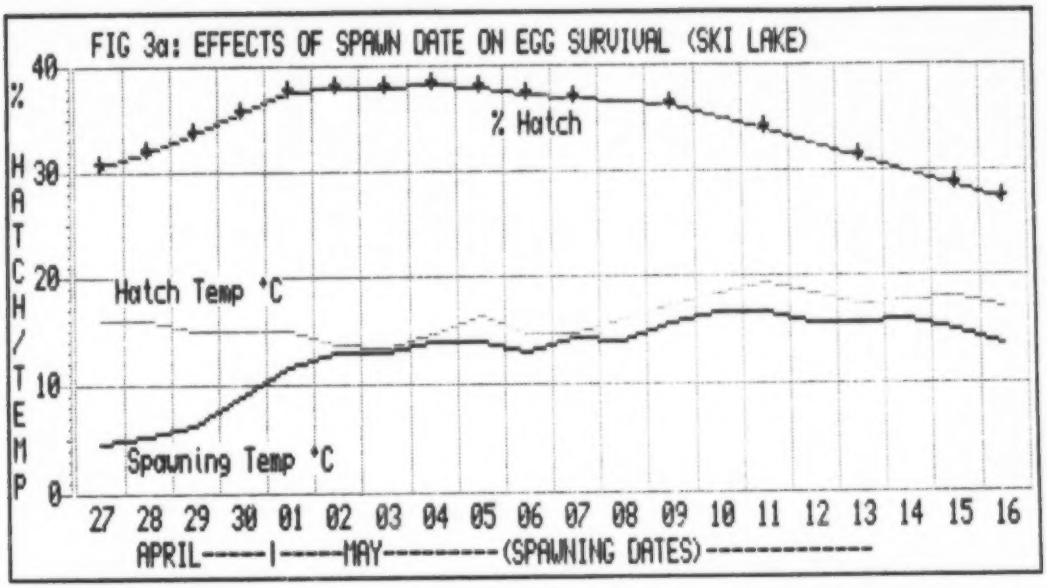
FIG 3a: EFFECTS OF SPAWN DATE ON EGG SURVIVAL (SKI LAKE)
% HATCH/TEMP
40
30
20
10
0
% Hatch
Hatch Temp °C
Spawning Temp °C
27 28 29 30 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16
APRIL-----|-----MAY---------(SPAWNING DATES)----------

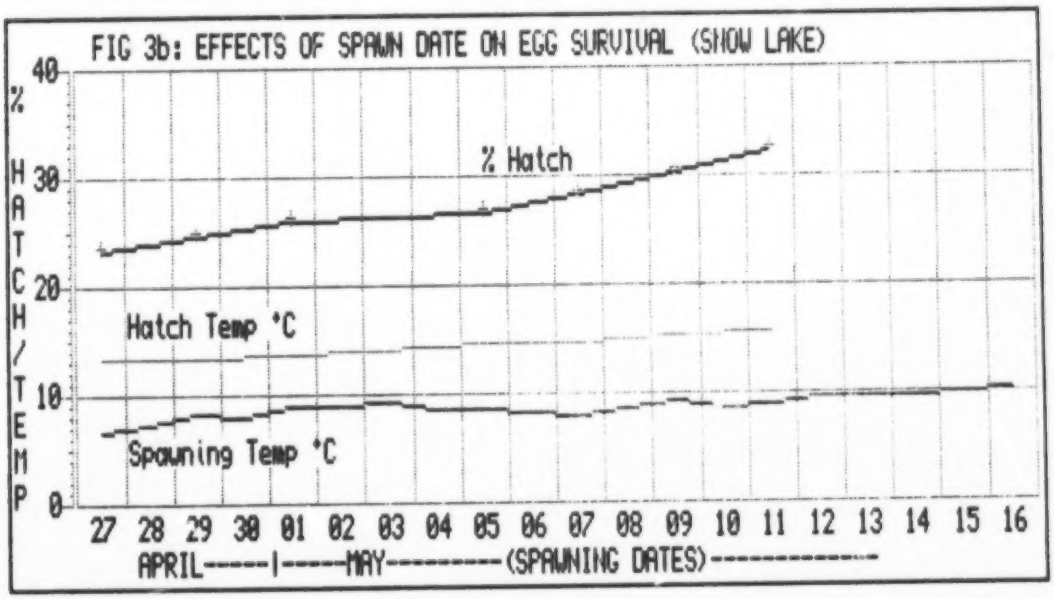
FIG 3b: EFFECTS OF SPAWN DATE ON EGG SURVIVAL (SNOW LAKE)
% HATCH/TEMP
40
30
20
10
0
% Hatch
Hatch Temp °C
Spawning Temp °C
27 28 29 30 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16
APRIL-----|-----MAY---------(SPAWNING DATES)----------

were near optimal (13 to 15°C) for all groups. Thus, the low predicted survival was the result of sub-optimal temperatures during the early (Block 1) development phase.

Spawning temperatures reported for walleye range from 5.6 to 11.1°C, with a preferred range of 6.5 to 8.9°C (Scott and Crossman, 1973). At Ski Lake, the entire temperature range was passed in 4 days (Figure 3a), while at Snow Lake, these temperatures prevailed from April 27 to May 18 (Figure 3b, Appendix 1). It should be noted that the reported spawning range is somewhat below the 10 to 15°C optimum for incubation of eggs (Ontario Hydro Research Division Report No 81-77-K), as the species appears to be adapted for spawning during the period of rapidly rising spring temperatures. The Ski Lake simulations (Figure 3a) suggest that while walleye might not be expected to spawn at that site after May 1 in 1985, the subsequent temperature regime was such that successful hatch would be expected for spawnings as late as May 9 (at 15.7°C).

3.2.2 Effects of Station Operation

Further simulations were run to assess the effects of various station operational modes (1, 2 or 3 shift/day operation) and temperature increase on walleye spawned at the Snow Lake outlet. These simulations were run for eggs spawned on April 27, May 4 and May 11. Results for the April 27 spawning are shown in Figure 4. As the ambient temperature regime was clearly below optimal temperature, moderate temperature increases would have a substantial beneficial effect. Best survival (43% hatch) is predicted for a 5 C° temperature rise and continuous (3 shift) operation, as compared with 23% hatch under ambient temperatures. With greater temperature increases, survival declines, approximating the ambient value at a ΔT of 9 C°. Survival would be minimal (<10%) at temperature rises of 10, 11 and 13 C° respectively for three, two and one shift operation.

Results for simulations using a May 4 spawning date are shown in Figure 5. These curves are very similar to those in Figure 4, but have been shifted slightly to the left (lower ΔT) due to warmer ambient temperatures. Thus, optimal survival (40% hatch) was obtained for continuous temperature increases over the 3 to 5 C° range and survival declined to "ambient" values when the ΔT reached 8 C°.

The effects of increased ambient temperatures are more pronounced for the May 11 spawning date (Figure 6). Optimal survival (38%) was predicted for a 3 C° temperature increase, and survival declined to "ambient" values with a 5 C° temperature rise. Minimal survival (<10%) was predicted at temperature increases of 8, 9 and 13 C° for 3, 2 and 1 shift operation. With two shift operation, substantial survival increases would be obtained

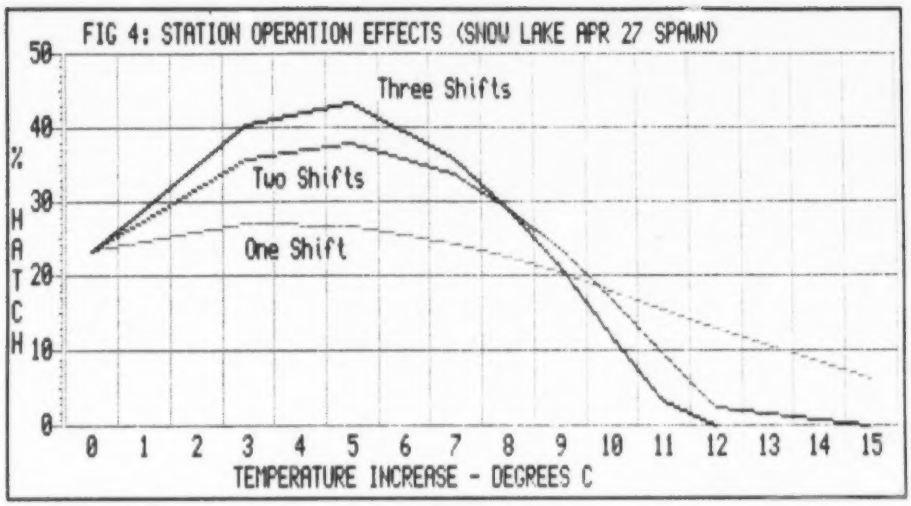
FIG 4: STATION OPERATION EFFECTS (SNOW LAKE APR 27 SPAWN)
Three Shifts
Two Shifts
One Shift
% HATCH
0 10 20 30 40 50
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
TEMPERATURE INCREASE - DEGREES C

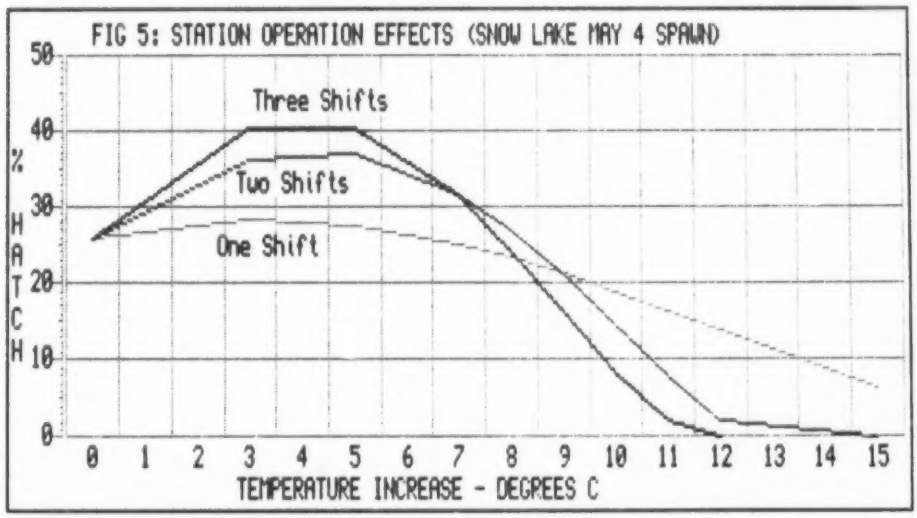
FIG 5: STATION OPERATION EFFECTS (SNOW LAKE MAY 4 SPAWN)
Three Shifts
Two Shifts
One Shift
% HATCH
0 10 20 30 40 50
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
TEMPERATURE INCREASE - DEGREES C

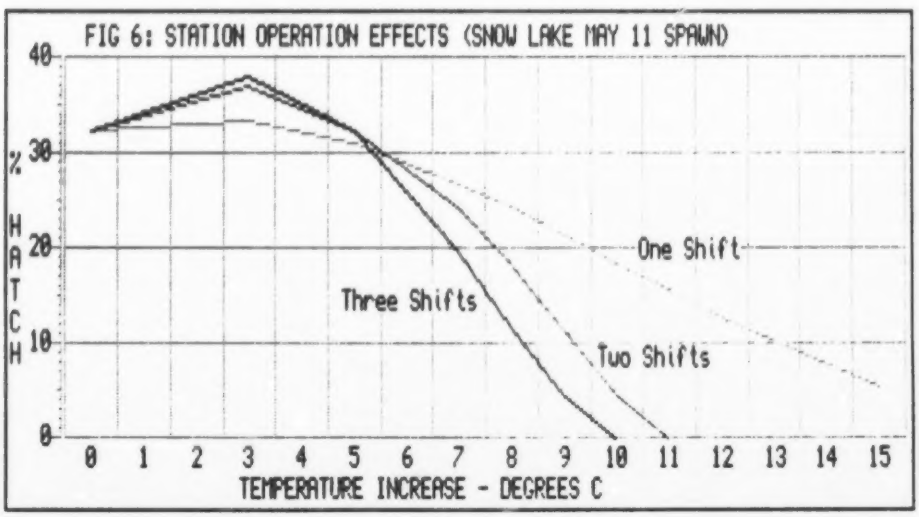
FIG 6: STATION OPERATION EFFECTS (SNOW LAKE MAY 11 SPAWN)
One Shift
Three Shifts
Two Shifts
% HATCH
0 10 20 30 40
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
TEMPERATURE INCREASE - DEGREES C

through operation of CCW pumps during the off-shift (compare two-shift and three-shift curves above 5 C^{o} ΔT).

While the above simulations have assumed a rapid daily temperature change with 1 shift or 2 shift operation, it is likely that Snow Lake will exert a substantial damping effect on such oscillations (Elliott, pers. comm.). If this is the case, then the curves for continuous operation (Figures 4 to 6) would provide the best estimate of station effects. Elliott has estimated the excess water temperatures (ΔT) at the Snow Lake outlet during April and May to be 6.3 to 9.0 C^{o} (1 shift operation), 8.4 to 10.0 C^{o} (2 shifts) and 9.3 to 10.4 C^{o} (3 shifts). For these calculations, the station ΔT and CCW flow were assumed to be 11.3 C^{o} and 6.6m^{3}/s, respectively. The calculations were performed using a plug-flow cooling pond model which assumed uniform vertical mixing. Elliott suggested that actual excess temperatures at the Snow Lake outlet may be somewhat lower than the computed values because the heated water would tend to float, thereby minimizing initial mixing and maximizing surface cooling. However, as this would also reduce the mixing volume and the transit time, exit temperatures may not be appreciably below the computed values.

If these computations are correct, operation of Atikokan TGS may adversely affect walleye spawning at the Snow Lake outlet. For example, the temperature rise for two shift operation may approximate a continuous 8.4 C^{o} (lowest computed value has been assumed due to Elliott's comments regarding surface cooling). Survival of early spawned eggs (April 27) would be similar to that expected for 1985 "ambient" conditions (23 - 25%; Figure 4). However, survival of eggs spawned on May 4 would decline to approximately 20% (Figure 5) and survival of eggs spawned on May 11 would decline to about 8% (Figure 6).

The presence of a heated discharge from Snow Lake throughout the spring may result in some advancement of spawning dates from the April 27 to May 11 range assumed here. Should this occur, present simulations suggest that better egg survival will likely result. However, from the computations presented in this report, the potential for deleterious effects clearly exists. Therefore, is it suggested that Snow Lake outflow temperatures be carefully monitored during the commissioning phases of station operation, and every attempt be made to minimize temperature rise during the spring period. Thus, it is suggested that the station begin "summer operations" (6.6 m^{3}/s CCW flow) as early as possible during the spring. Monitoring of the spawning time, plus in-situ incubation studies of walleye eggs at the Snow Lake outlet should aid in assessing any impact.

4.0 SUMMARY AND CONCLUSIONS

1. Simulations based on 1985 ambient temperatures indicated that walleye spawned on April 27 would have completed hatch by May 14 at the Ski Lake outlet and by May 25 at the Snow Lake outlet. Delay of spawning by two weeks (to May 11) would result in hatch dates of May 24 (10 day delay) at Ski Lake and May 31 (6 day delay) at Snow Lake.

2. Effects of heat additions (from station operation) on hatch dates were examined in detail for Snow Lake fish. Hatch advancement would be greatest for early spawned eggs, due to cooler ambient temperatures. With a 10 C^{o} continuous ΔT, advancement would amount to 18 days for eggs spawned on April 27 and 12 days for eggs spawned on May 11. With a 5 C^{o} continuous ΔT, hatch would be advanced by 12 days for April 27 spawning and 8 days (to May 23) for May 11 spawning. Assuming that the ΔT will be at least 5 C^{o}, flow should be maintained until May 23.

3. Ambient temperatures at Ski Lake were favourable for walleye egg survival, especially if spawning were delayed until temperatures reached 10°C (May 1). Predicted survivals ranged from 35 to 38% for eggs spawned over the May 1 to May 9 period (compared with a laboratory optimum of 44%). At the Snow Lake outlet, ambient temperatures were clearly sub-optimal, as the station operated CCW pumps with little or no heat input. Predicted survival rate ranged from 23% (April 27 spawning) to 32% (May 11 spawning).

4. Further simulations were run with Snow Lake data to assess possible effects of station operation on walleye egg survival. Results for early spawning (April 27) indicated best survival (43%) with a 5 C^{o} ΔT. For May 4 spawning, best survival (40%) occurred over the 3 to 5 C^{o} ΔT range, while best survival (38%) was predicted for a 3 C^{o} ΔT with May 11 spawning. A decrease in egg survival below "ambient" levels was predicted for temperature rises of 9, 8 and 5 C^{o} respectively for April 27, May 4 and May 11 spawning dates. Results indicated that if temperature increases at the Snow Lake outlet exceed these values and the station is operating for 2 shifts/day, some improvement in walleye egg survival may be gained by operation of CCW pumps during the off-shift.

5. Computations by R. Elliott suggest that Snow Lake may exert a substantial damping effect on daily temperature cycles, and expected temperature elevations at the lake outlet are quite high (8.4 to 10.0 C^{o} for 2 shift operation). Even assuming the lower limit of this range, due to thermal stratification and increased heat loss as the discharge water enters Snow

Lake, present simulations suggest that walleye eggs may be deleteriously affected, especially if spawning is delayed (into May). Thus, detailed monitoring of Snow Lake outflow temperatures, monitoring of walleye spawning times and hatch success are recommended to assess any impact.

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APPENDIX 1

ATIKOKAN 1985 AMBIENT TEMPERATURES USED IN
WALLEYE EGG SIMULATION STUDIES

(DATA FROM GEOTECHNICAL & HYDRAULIC ENGINEERING DEPT.)

Date	Snow Lake Outlet	Ski Lake Outlet
April		
27	6.8	4.7
28	7.5	5.6
29	8.3	6.5
30	8.2	9.2
May		
1	9.0	11.9
2	9.1	13.0
3	9.5	13.2
4	8.8	14.0
5	8.6	14.0
6	8.3	13.2
7	8.2	14.4
8	8.7	14.2
9	9.4	15.7
10	8.8	16.8
11	9.1	16.6
12	9.6	15.7
13	9.8	15.6
14	9.9	16.0
15	10.0	15.0
16	10.4	13.6
17	10.7	13.3
18	11.2	14.6
19	11.7	16.3
20	11.5	14.8
21	11.8	14.7
22	12.5	15.6
23	13.1	17.3
24	14.0	19.2
25	13.3	17.5
26	13.4	17.2
27	13.8	17.9
28	14.3	17.1
29	14.8	end
30	15.3	of
31	15.7	data

APPENDIX 2

PREDICTED EFFECTS OF SPAWNING DATES ON

WALLEYE HATCH DATES AND SURVIVAL

(AMBIENT TEMPERATURES)

Spawning Date	Snow Lake		Ski Lake	
	Hatch Date	% Survival	Hatch Date	% Survival
April 27	May 25	23.31	May 14	30.42
April 28	------	-----	May 14	31.91
April 29	May 26	24.70	May 15	33.71
April 30	------	-----	May 15	35.74
May 1	May 27	25.92	May 15	37.40
May 2	------	-----	May 16	37.78
May 3	------	-----	May 17	37.95
May 4	May 28	25.80	May 18	38.11
May 5	May 29	26.47	May 19	37.73
May 6	------	-----	May 20	37.05
May 7	May 29	28.31	May 21	36.91
May 9	May 30	30.39	May 23	36.11
May 11	May 31	32.19	May 24	33.76
May 13	---end of data---		May 26	31.28
May 15			May 27	28.69
May 16			May 28	27.42

APPENDIX 3

PREDICTED EFFECTS OF TEMPERATURE INCREASE ON WALLEYE HATCH DATES AND SURVIVAL (SNOW LAKE OUTLET)

	----- Spawning Dates -----					
	April 27		May 4		May 11	
Temperature Rise and % of Time *	Hatch Date	% Surv	Hatch Date	% Surv	Hatch Date	% Surv
Ambient	May 25	23.31	May 28	25.80	May 31	32.19
+3, 25%	May 23	27.11	May 26	28.41	May 29	33.06
+3, 75%	May 19	35.61	May 23	36.22	May 27	36.80
+3, 100%	May 17	40.25	May 22	40.30	May 26	37.81
+5, 25%	May 21	26.66	May 24	27.55	May 28	30.78
+5, 75%	May 15	37.69	May 20	36.87	May 24	32.30
+5, 100%	May 13	43.04	May 19	40.51	May 23	32.15
+7, 25%	May 19	24.24	May 23	25.20	May 27	26.71
+7, 75%	May 12	33.55	May 18	31.80	May 23	24.15
+7, 100%	May 10	35.95	May 16	31.62	May 21	19.66
+8, 25%	May 18	22.40	May 22	23.41	May 26	24.19
+8, 75%	May 10	29.16	May 16	27.07	May 22	18.18
+8, 100%	May 9	29.33	May 15	24.35	May 21	11.82
+9, 25%	May 17	20.30	May 22	21.28	May 26	21.41
+9, 75%	May 9	23.59	May 15	21.18	May 21	11.43
+9, 100%	May 8	21.18	May 14	16.32	May 20	4.40
+10, 25%	May 16	18.01	May 21	18.86	May 25	18.53
+10, 75%	May 8	17.19	May 14	14.58	May 20	4.69
+10, 100%	May 7	12.11	May 13	8.64	May 19	0.00
+11, 25%	May 15	15.63	May 20	16.31	May 25	15.62
+11, 75%	May 7	9.90	May 13	8.03	May 19	0.00
+11, 100%	May 6	3.68	May 13	2.21	------	-----
+12, 25%	May 14	13.21	May 19	13.73	May 24	12.83
+12, 75%	May 6	2.71	May 12	2.10	May 18	0.00
+12, 100%	May 5	0.00	May 12	0.00	------	-----
+15, 25%	May 11	6.42	May 18	6.64	May 23	5.48
+15, 75%	May 3	0.00	May 10	0.00	------	-----

* 25% = Temperature increased for 6 hours/day
75% = Temperature increased for 18 hours/day
100% = Temperature increased continuously

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